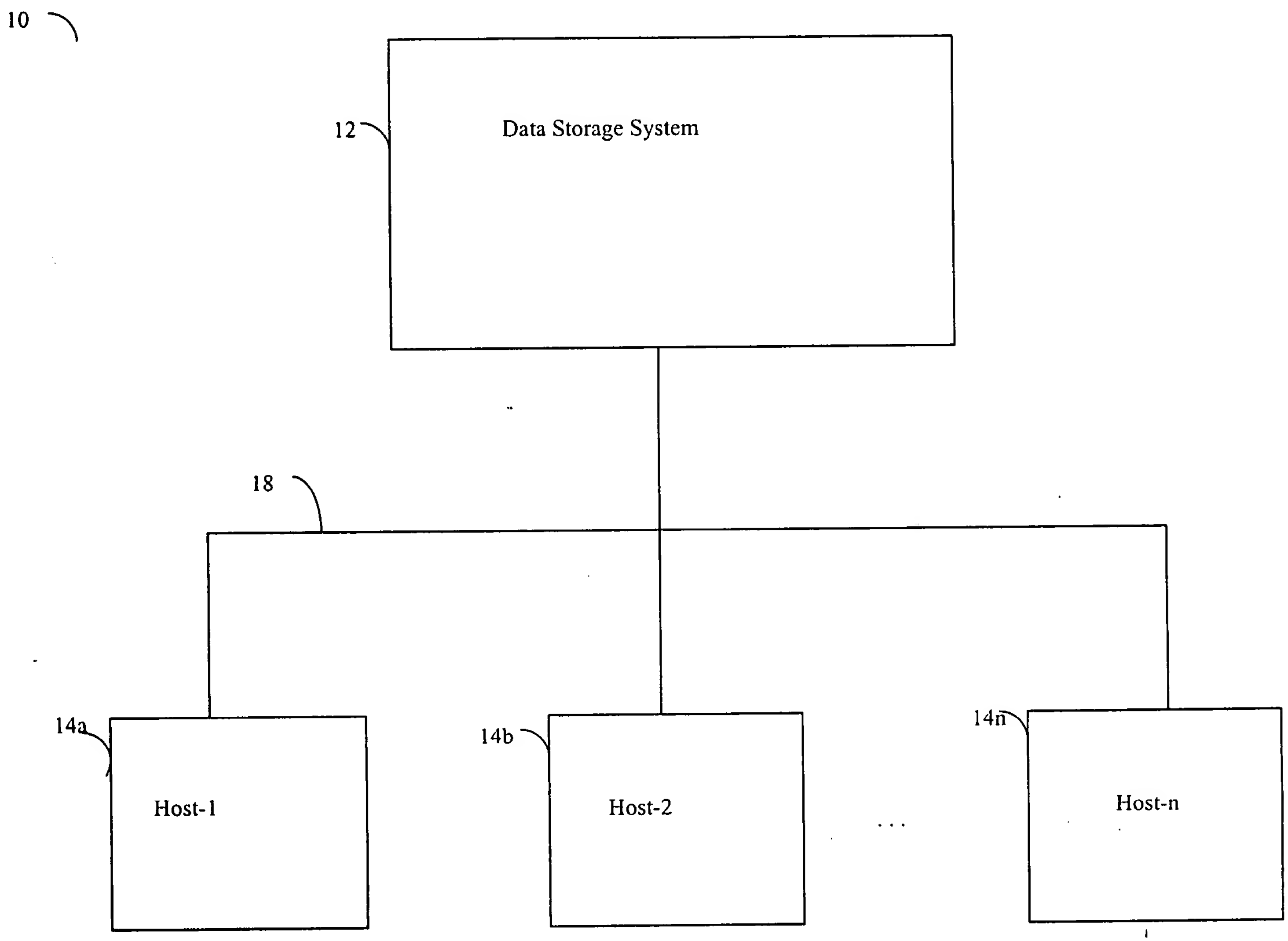


FIGURE 1

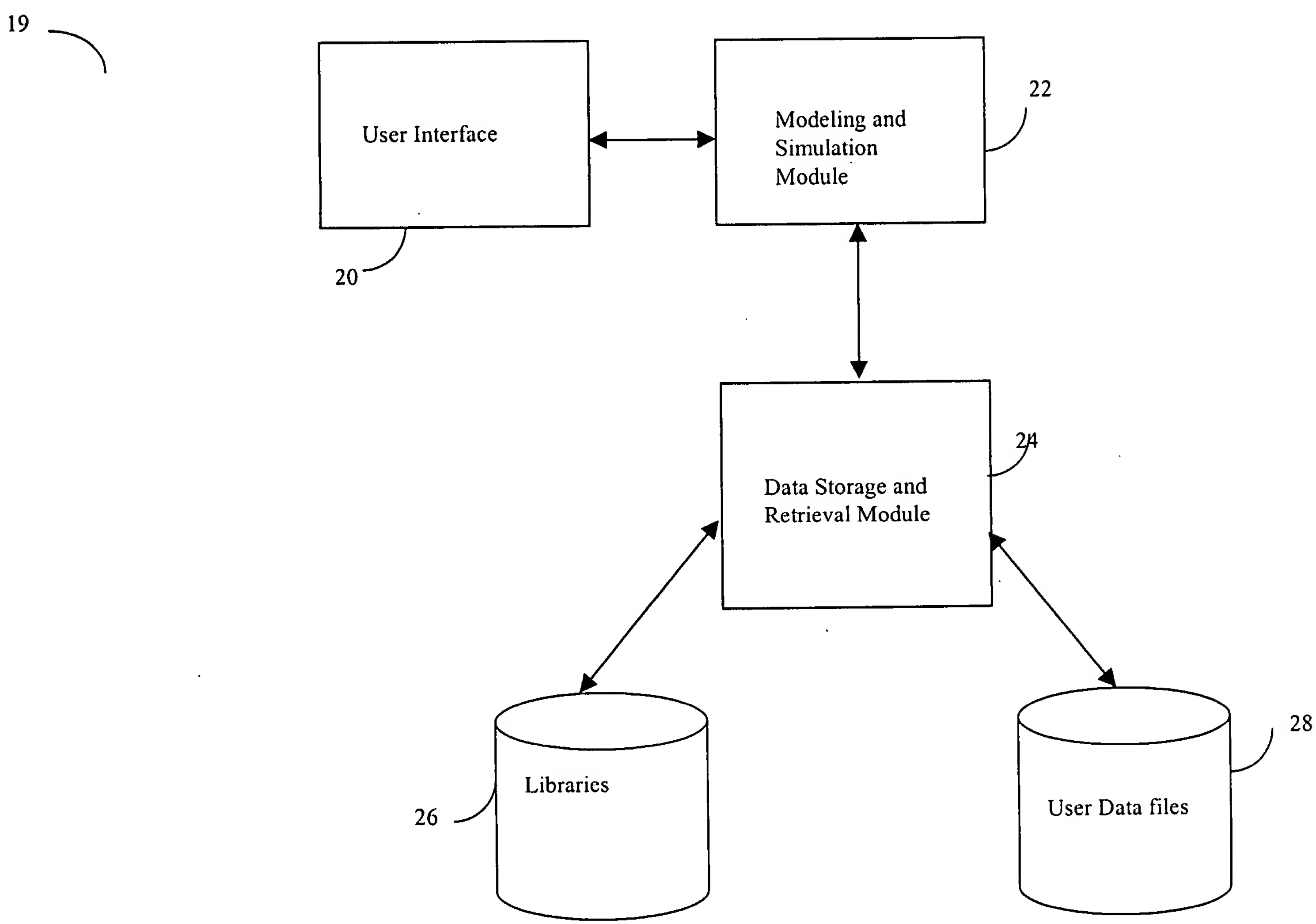
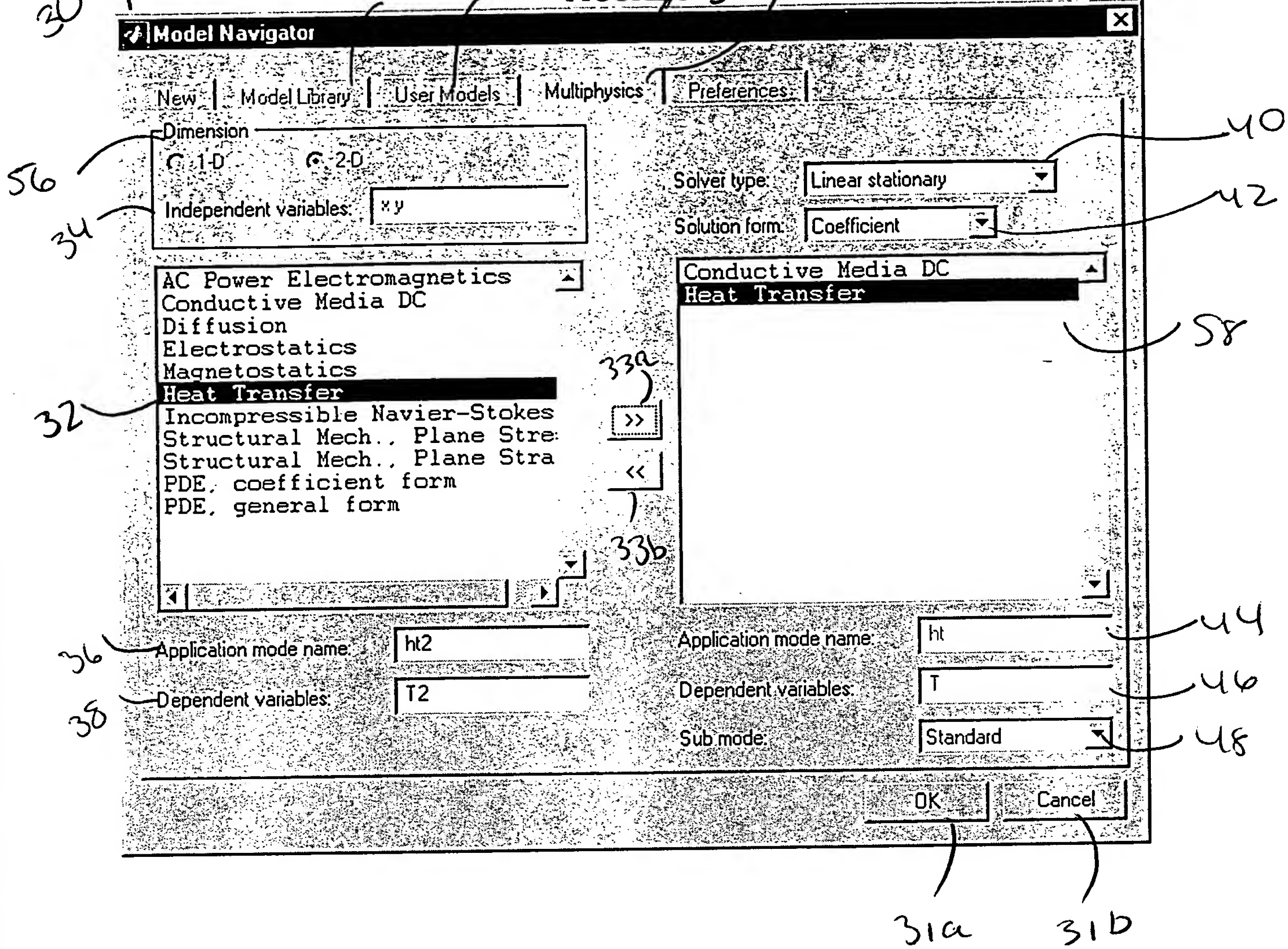

19
User Interface
20
Modeling and
Simulation
Module
22
Data Storage and
Retrieval Module
24
Libraries
26
User Data files
28

FIGURE 2

FIGURE 3



Model Navigator
New
Model Library
User Models
Multiphysics
Preferences
Dimension
1-D
2-D
Independent variables:
x y
Solver type:
Linear stationary
Solution form:
Coefficient
AC Power Electromagnetics
Conductive Media DC
Diffusion
Electrostatics
Magnetostatics
Heat Transfer
Incompressible Navier-Stokes
Structural Mech., Plane Stre:
Structural Mech., Plane Stra
PDE, coefficient form
PDE, general form
Conductive Media DC
Heat Transfer
Application mode name:
ht2
Dependent variables:
T2
Application mode name:
ht
Dependent variables:
T
Sub mode:
Standard
OK
Cancel
30
50
52
54
56
34
40
42
32
33a
33b
58
36
38
44
46
48
31a
31b

FIGURE ~~2~~ 4

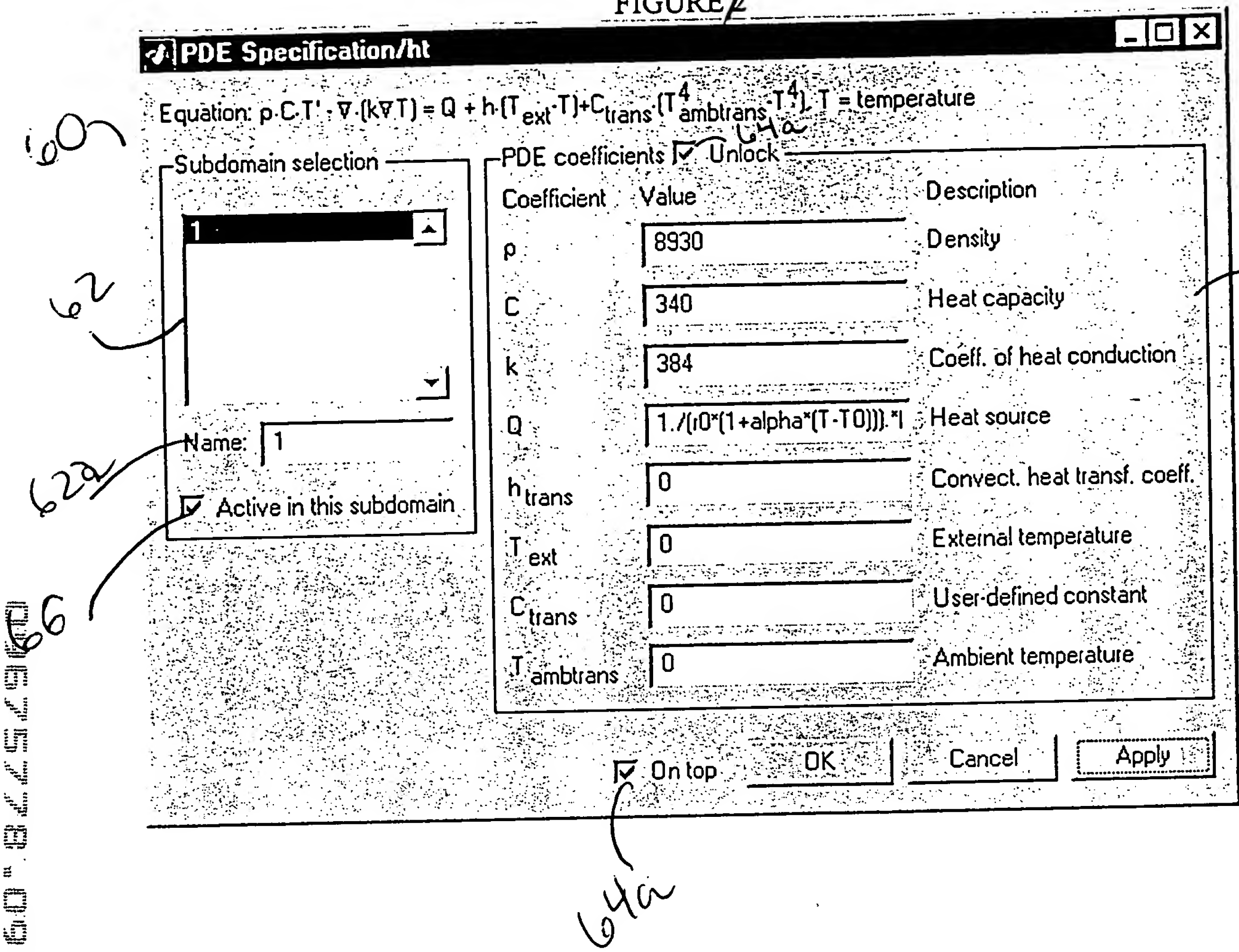

PDE Specification/ht
Equation: ρ·C·T' - ∇·(k∇T) = Q + h·(T_ext - T)+C_trans·(T⁴_ambtrans - T⁴), T = temperature
Subdomain selection
1
Name: 1
Active in this subdomain
PDE coefficients
Unlock
Coefficient
Value
Description
ρ
8930
Density
C
340
Heat capacity
k
384
Coeff. of heat conduction
Q
1./(r0*(1+alpha*(T-T0))).*I
Heat source
h_trans
0
Convect. heat transf. coeff.
T_ext
0
External temperature
C_trans
0
User-defined constant
T_ambtrans
0
Ambient temperature
On top
OK
Cancel
Apply
60
62
62a
64a
64
66
64a

FIGURE ~~3~~ 5

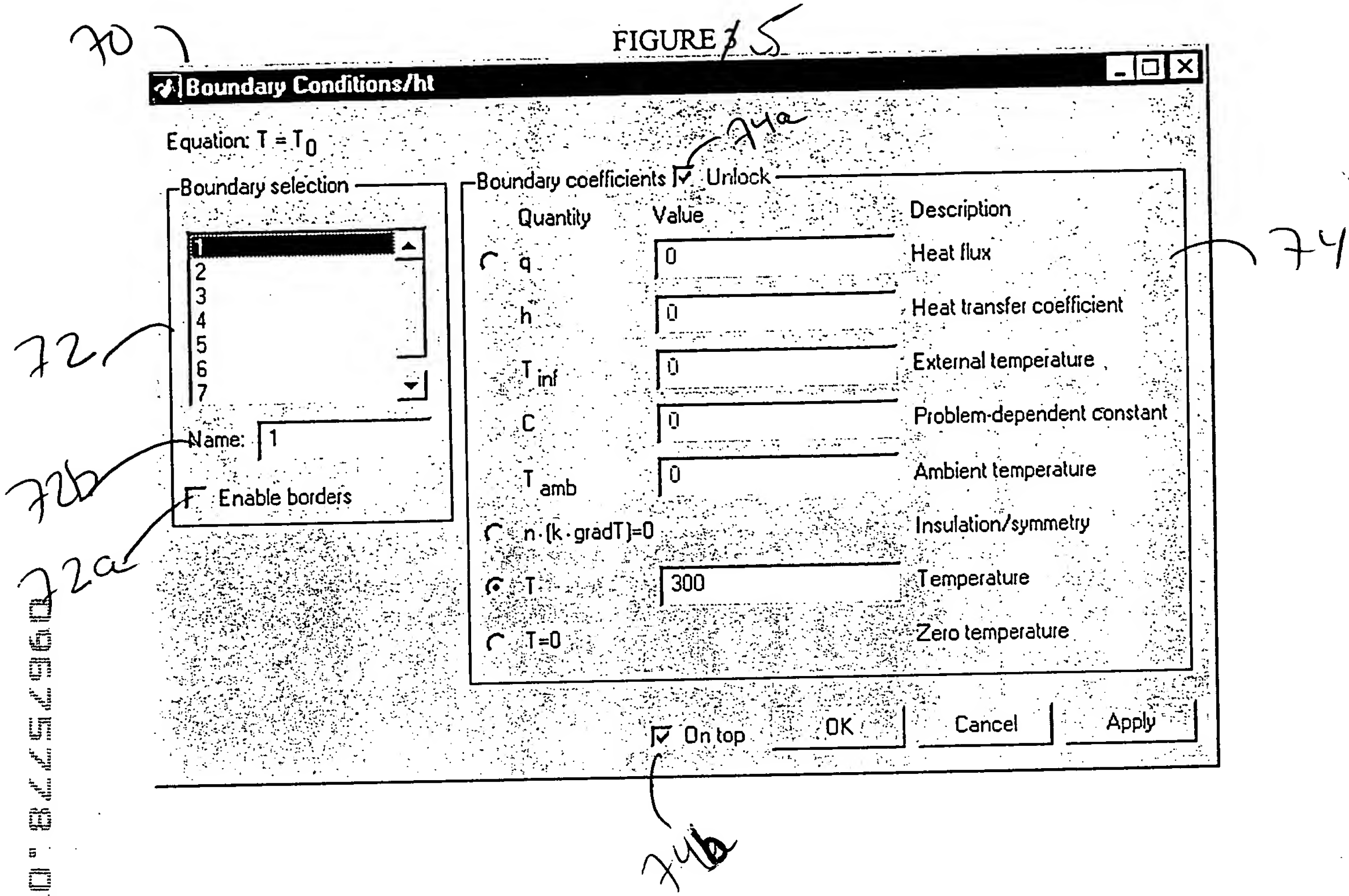
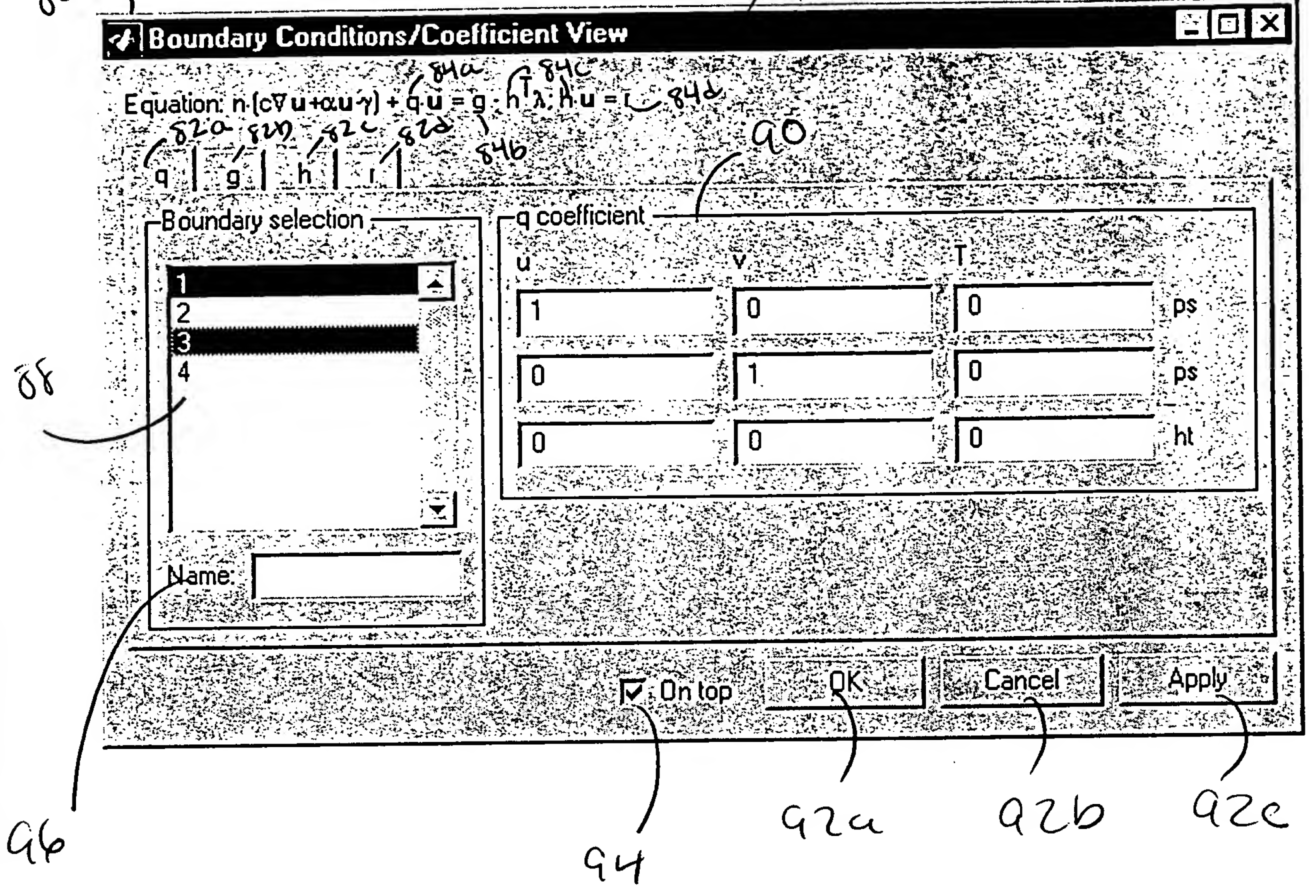

70
Boundary Conditions/ht
Equation: T = T0
Boundary selection
1
2
3
4
5
6
7
Name: 1
Enable borders
72
72a
72b
Boundary coefficients
Unlock
74a
Quantity
Value
Description
q
0
Heat flux
h
0
Heat transfer coefficient
T inf
0
External temperature
C
0
Problem-dependent constant
T amb
0
Ambient temperature
n·(k·gradT)=0
Insulation/symmetry
T
300
Temperature
T=0
Zero temperature
74
On top
OK
Cancel
Apply
74b

FIGURE ~~4~~ 6


Boundary Conditions/Coefficient View
Equation: n·(c∇u+αu·γ) + q·u = g · hᵀλ; h·u = r
q
g
h
r
Boundary selection
1
2
3
4
Name:
q coefficient
u
v
T
1
0
0
ps
0
1
0
ps
0
0
0
ht
On top
OK
Cancel
Apply
80
82a
82b
82c
82d
84a
84b
84c
84d
88
90
92a
92b
92c
94
96

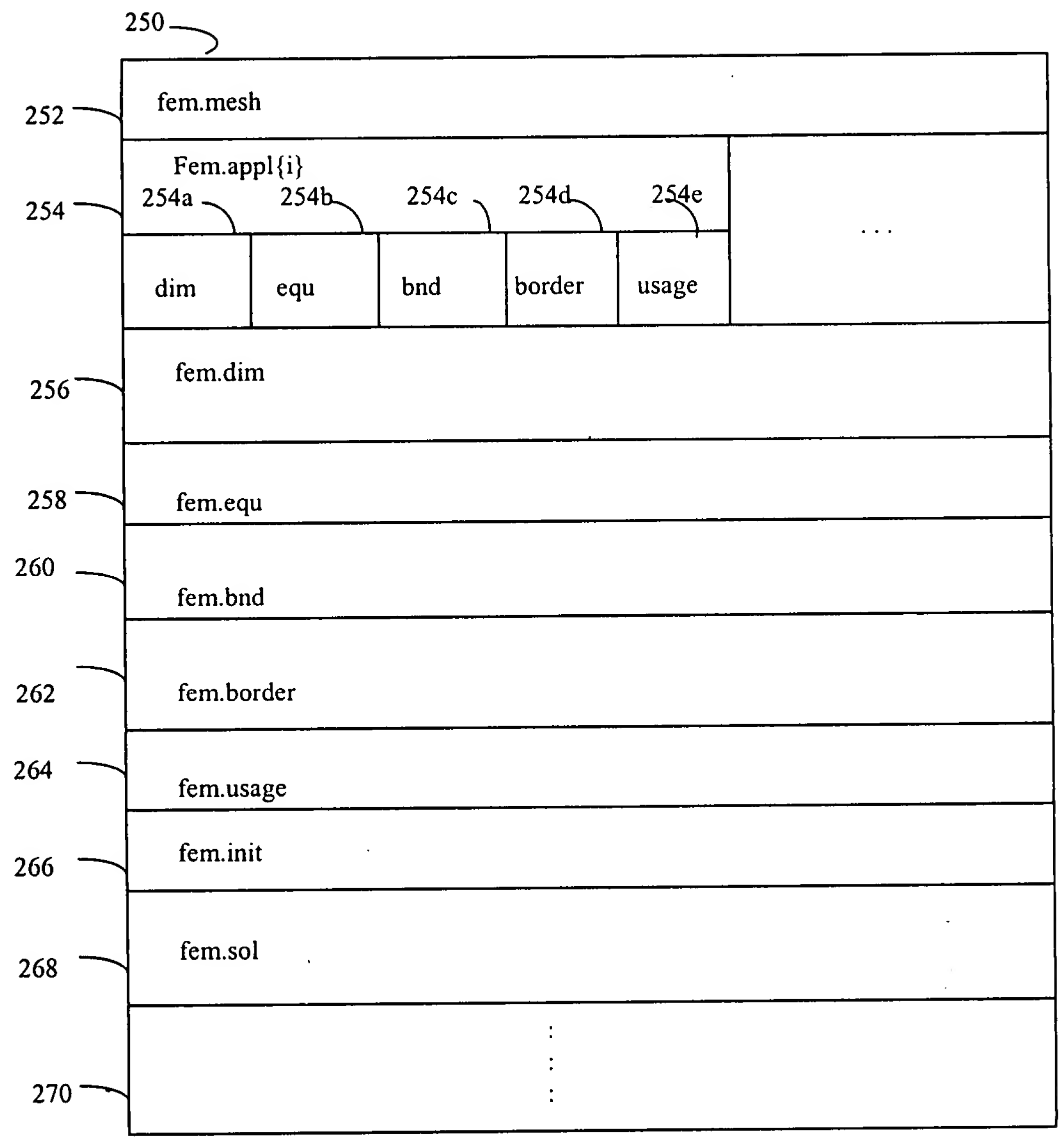
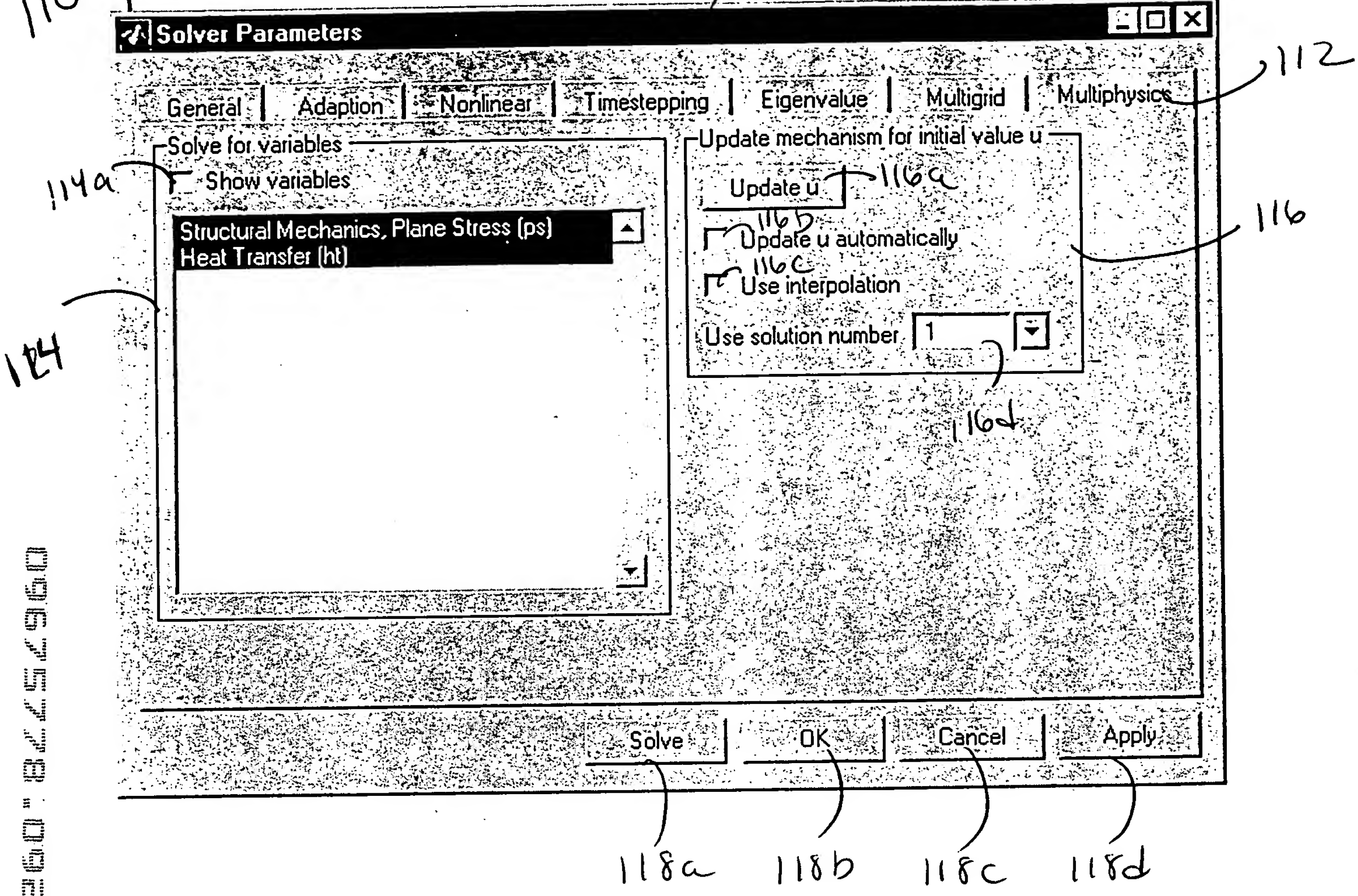

250
fem.mesh
252
Fem.appl{i}
254
254a
254b
254c
254d
254e
dim
equ
bnd
border
usage
...
fem.dim
256
fem.equ
258
fem.bnd
260
fem.border
262
fem.usage
264
fem.init
266
fem.sol
268
270

FIGURE 6A

FIGURE 5/7



110
Solver Parameters
General
Adaption
Nonlinear
Timestepping
Eigenvalue
Multigrid
Multiphysics
112
Solve for variables
114a
Show variables
Structural Mechanics, Plane Stress (ps)
Heat Transfer (ht)
124
Update mechanism for initial value u
Update u
116a
116b
Update u automatically
116c
Use interpolation
116
Use solution number
1
116d
Solve
OK
Cancel
Apply
118a
118b
118c
118d

FIGURE ~~6~~ 8

140

$$
\begin{cases}
d_{a\,lk}\dfrac{\partial u_k}{\partial t} - \dfrac{\partial}{\partial x_j}\left(c_{lkji}\dfrac{\partial u_k}{\partial x_i} + \alpha_{lkj}u_k - \gamma_{lj}\right) + \beta_{lki}\dfrac{\partial u_k}{\partial x_i} + a_{lk}u_k = f_l & \Omega \quad 142 \\[2ex]
n_j\left(c_{lkji}\dfrac{\partial u_k}{\partial x_i} + \alpha_{lkj}u_k - \gamma_{lj}\right) + q_{lk}u_k = g_l - h_{ml}\lambda_m & \partial\Omega \quad 146a \\[2ex]
h_{ml}u_l = r_m & \partial\Omega \quad 146b
\end{cases}
\quad 146
$$

FIGURE ~~7~~ 9

150

$$
\begin{cases}
d_{a\,lk}\dfrac{\partial u_k}{\partial t} + \dfrac{\partial \Gamma_{lj}}{\partial x_j} = F_l & \Omega \quad 152 \\[2ex]
-n_j\Gamma_{lj} = G_l + \dfrac{\partial R_m}{\partial u_l}\lambda_m & \partial\Omega \quad 154a \\[2ex]
0 = R_m & \partial\Omega \quad 154b
\end{cases}
\quad 154
$$

FIGURE 10

324

$$\left\{\begin{array}{ll}
\gamma_{lj} = \Gamma_{lj} & f_l = F_l \\
c_{lkji} = -\dfrac{\partial \Gamma_{lj}}{\partial\left(\dfrac{\partial u_k}{\partial x_i}\right)} & \alpha_{lkj} = -\dfrac{\partial \Gamma_{lj}}{\partial u_k} \\
\beta_{lki} = -\dfrac{\partial F_l}{\partial\left(\dfrac{\partial u_k}{\partial x_i}\right)} & a_{lk} = -\dfrac{\partial F_l}{\partial u_k} \\
g_l = G_l & r_l = R_l \\
q_{lk} = -\dfrac{\partial G_l}{\partial u_k} & h_{lk} = -\dfrac{\partial R_l}{\partial u_k}
\end{array}\right.$$

FIGURE ~~8~~ 11

$$240\left\{\begin{aligned}
\Gamma_{lj} &= -c_{lkji}\frac{\partial u_k}{\partial x_i} - \alpha_{lkj}u_k + \gamma_{lj}\\
F_l &= f_l - \beta_{lki}\frac{\partial u_k}{\partial x_i} - a_{lk}u_k\\
G_l &= g_l - q_{lk}u_k\\
R_m &= r_m - h_{ml}u_l
\end{aligned}\right.$$

FIG 12

300

$$\left\{\begin{array}{l}
\int_{\Omega}\left(\left(c_{lkji}\frac{\partial u_k}{\partial x_i}+\alpha_{lkj}u_k\right)\frac{\partial v}{\partial x_j}+\left(d_{a\,lk}\frac{\partial u_k}{\partial t}+\beta_{lki}\frac{\partial u_k}{\partial x_i}+a_{lk}u_k\right)v\right)dx+ \\
\int_{\partial\Omega} q_{lk}u_k v\,ds=\int_{\Omega}\left(\gamma_{lj}\frac{\partial v}{\partial x_j}+f_l v\right)dx+\int_{\partial\Omega}(g_l-h_{ml}\lambda_m)v\,ds \\
\int_{\partial\Omega}\mu h_{mk}u_k\,ds=\int_{\partial\Omega}\mu r_m\,ds
\end{array}\right.$$

FIG 13

$$302\;\left\{\begin{aligned}&\int_{\Omega}\left(\Gamma_{lj}\frac{\partial v}{\partial x_j}+F_l v-d_{alk}\frac{\partial u_k}{\partial t}v\right)dx+\int_{\partial\Omega}\left(G_l+\frac{\partial R_m}{\partial u_l}\lambda_m\right)v\,ds=0\\&\int_{\partial\Omega}R_m\mu\,ds=0\end{aligned}\right.$$

FIG 14

304

$$U_k(x) = \sum_{I=1}^{N_p} U_{I,k}\phi_I(x), \qquad \Lambda_m(x) = \sum_{K=1}^{N_e}\sum_{L=1}^{n} \Lambda_{K,L,m}\Psi_{K,L}(x).$$

FIG 15

206

$$
\left\{
\begin{aligned}
&\int_\tau \left(c_{lkji} U_{I,k} \frac{\partial \phi_I}{\partial x_i} + \alpha_{lkj} U_{I,k} \phi_I \right) \frac{\partial \phi_J}{\partial x_j} dx + \\
&\int_\tau \left(d_{a\,lk} \frac{\partial U_{I,k}}{\partial t} \phi_I + \beta_{lki} U_{I,k} \frac{\partial \phi_I}{\partial x_i} + a_{lk} U_{I,k} \phi_I \right) \phi_J dx + \\
&\int_{\partial\tau} q_{lk} U_{I,k} \phi_I \phi_J ds = \int_\tau \left(\gamma_{lj} \frac{\partial \phi_J}{\partial x_j} + f_l \phi_J \right) dx + \\
&\int_{\partial\tau} (g_l - h_{ml} \Lambda_{K,L,m} \Psi_{K,L}) \phi_J ds
\end{aligned}
\right.
$$

FIG 16

308

$$\int_{\partial\tau} h_{m\,k} U_{I,\,k} \phi_I \Psi_{K,\,L}\, ds = \int_{\partial\tau} r_m \Psi_{K,\,L}\, ds$$

FIG 17

$$312\begin{cases}\int_{\tau}\left(\Gamma_{lj}\frac{\partial\phi_J}{\partial x_j}+F_l\phi_J-d_{alk}\frac{\partial u_k}{\partial t}\phi_J\right)dx+\int_{\partial\tau}\left(G_l+\frac{\partial R_m}{\partial u_l}\Lambda_{K,L,m}\Psi_{K,L}\right)\phi_J\,ds=0\\ \int_{\partial\tau}R_m\Psi_{K,L}\,ds=0\end{cases}$$

FIG 18

310

$$DA_{(J,I),(I,k)} = \int_\tau d_{a\,lk} \phi_I \phi_J \, dx$$

$$C_{(J,I),(I,k)} = \int_\tau c_{lkji} \frac{\partial \phi_I}{\partial x_i} ? \frac{\partial \phi_J}{\partial x_j} \, dx$$

$$AL_{(J,I),(I,k)} = \int_\tau \alpha_{lkj} \phi_I ? \frac{\partial \phi_J}{\partial x_j} \, dx$$

$$BE_{(J,I),(I,k)} = \int_\tau \beta_{lki} \frac{\partial \phi_I}{\partial x_i} \phi_J \, dx$$

$$A_{(J,I),(I,k)} = \int_\tau a_{lk} \phi_I \phi_J \, dx$$

$$Q_{(J,I),(I,k)} = \int_{\partial\tau} q_{lk} \phi_I \phi_J \, ds$$

$$GA_{(J,I)} = \int_\tau \gamma_{lj} \frac{\partial \phi_J}{\partial x_j} \, dx$$

$$F_{(J,I)} = \int_\tau f_l \phi_J \, dx$$

$$G_{(J,I)} = \int_{\partial\tau} g_l \phi_J \, ds$$

$$H_{(K,L,m),(I,k)} = \int_{\partial\tau} h_{mk} \phi_I \Psi_{K,L} \, ds$$

$$R_{(K,L,m)} = \int_{\partial\tau} r_m \Psi_{K,L} \, ds$$

FIG 19

320
$$\begin{cases} DA\dfrac{\partial U}{\partial t} + (C + AL + BE + A + Q)U + H^{T}\Lambda = GA + F + G \\ HU = R \end{cases}$$

FIG 20

$$322 \begin{cases} DA\dfrac{\partial U}{\partial t} + H^{T}\Lambda = GA + F + G \\ R = 0 \end{cases}$$

FIG 21

326 $$\begin{cases} J(U^{(k)})\Delta U^{(k)} = -\rho(U^{(k)}) \\ U^{(k+1)} = U^{(k)} + \lambda_k \Delta U^{(k)} \end{cases}$$

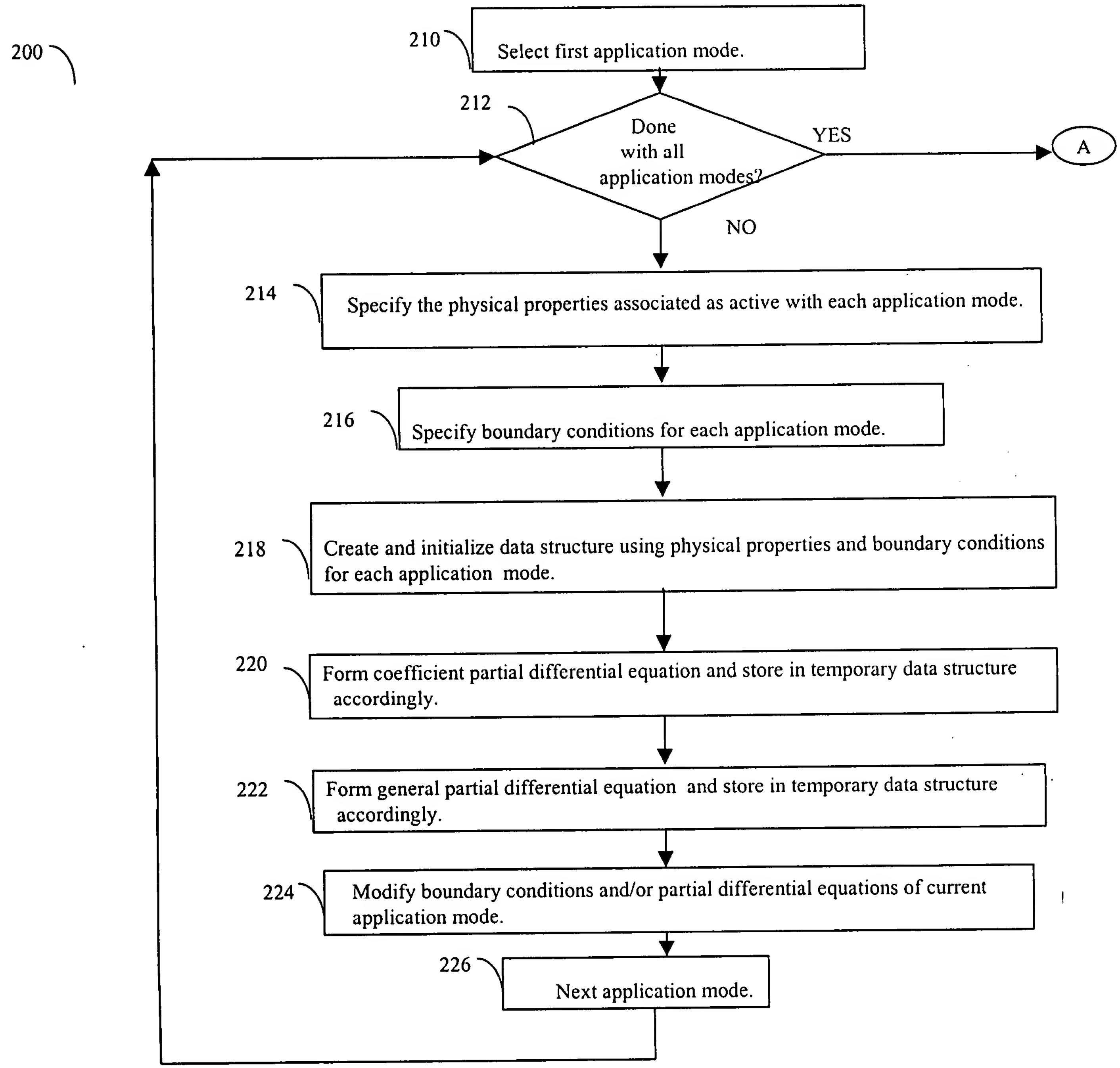

200
210
Select first application mode.
212
Done with all application modes?
YES
A
NO
214
Specify the physical properties associated as active with each application mode.
216
Specify boundary conditions for each application mode.
218
Create and initialize data structure using physical properties and boundary conditions for each application mode.
220
Form coefficient partial differential equation and store in temporary data structure accordingly.
222
Form general partial differential equation and store in temporary data structure accordingly.
224
Modify boundary conditions and/or partial differential equations of current application mode.
226
Next application mode.

FIGURE 22

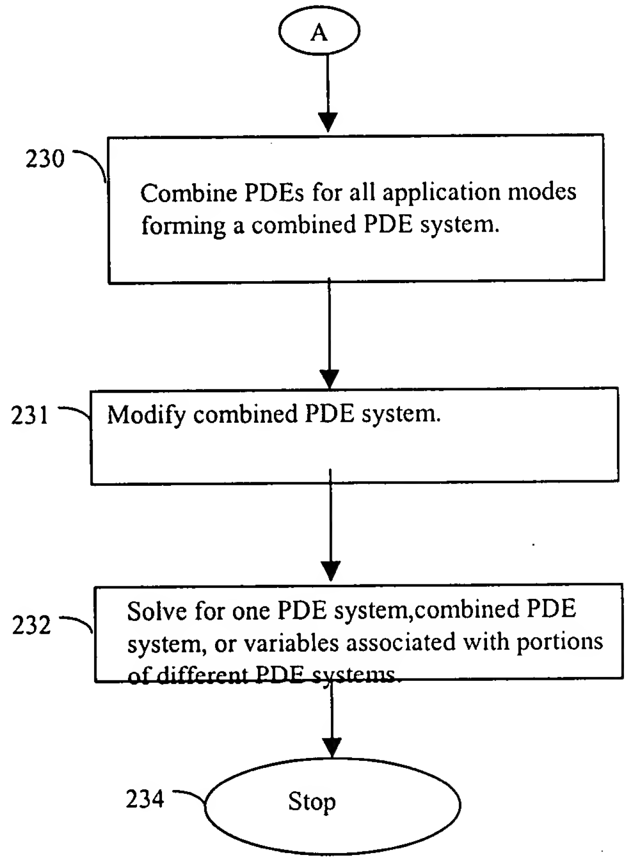
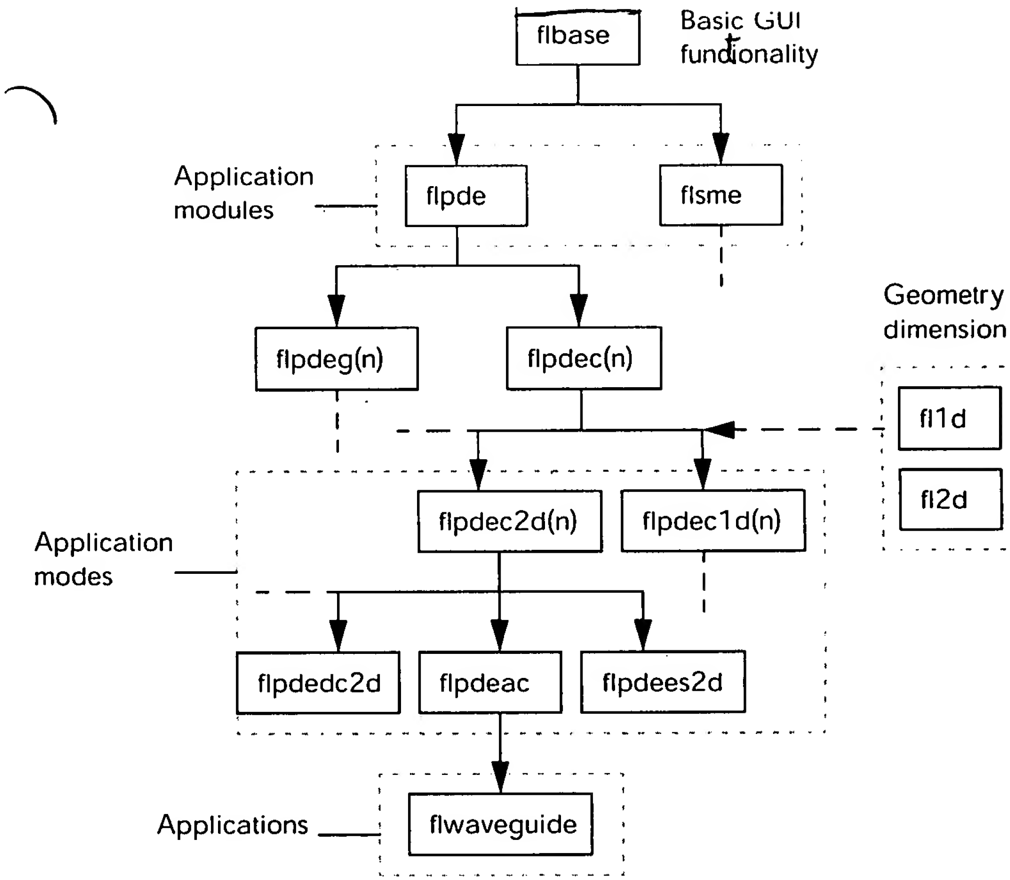

A
230
Combine PDEs for all application modes forming a combined PDE system.
231
Modify combined PDE system.
232
Solve for one PDE system,combined PDE system, or variables associated with portions of different PDE systems.
234
Stop

FIGURE 23

500



The class hierarchy of FEMLAB

FIGURE 24

1-D Physics Application Modes

Application mode	Class name	Parent class
Diffusion	flpdedf1d	flpdedf
Heat Transfer	flpdeht1d	flpdeht

502

1-D PDE Application Modes

Application mode	Class name	Parent class
Coefficient PDE model, n variables	flpdec1d*(n)*	flpdec*(n)*
General PDE model, n variables	flpdeg1d*(n)*	flpdeg*(n)*

504

FIGURE 25

2-D Physics Application Modes

Application mode	Class name	Parent class
AC Power Electromagnetics	`flpdeac`	`flpdec2d`
Conductive Media DC	`flpdedc2d`	`flpdedc`
Diffusion	`flpdedf2d`	`flpdedf`
Electrostatics	`flpdees2d`	`flpdees`
Magnetostatics	`flpdems2d`	`flpdems`
Heat Transfer	`flpdeht2d`	`flpdeht`
Incompressible Navier-Stokes	`flpdens2d`	`flpdens`
Structural Mechanics, Plane Stress	`flpdeps`	`flpdec2d`
Structural Mechanics, Plane Strain	`flpdepn`	`flpdec2d`

506

PDE Application Modes

Application mode	Class name	Parent class
Coefficient PDE model, n variables	`flpdec2d`*(n)*	`flpdec`*(n)*
General PDE model, n variables	`flpdeg2d`*(n)*	`flpdeg`*(n)*

508

FIGURE 26

Application Object Properties

Property name	Description	Data type
`dim`	Names of the dependent variables	Cell array of strings
`form`	PDE form	String (`coefficient`/`general`)
`name`	Application name	String
`parent`	Parent class names	String, cell array of strings, or the empty matrix
`sdim`	Names of the independent variables (space dimensions)	Cell array of strings
`submode`	Name of current submode	String (`std`/`wave`)
`tdiff`	Time differentiation flag	String (`on`/`off`)

510

FIGURE 27

00609027.082502

512

```
function obj = myapp()
%MYAPP Constructor for a FEMLAB application object.

obj.name = 'My first FEMLAB application';
obj.parent = 'flpdeht2d';

% MYAPP is a subclass of FLPDEHT2D:
p1 = flpdeht2d;
obj = class(obj,'myapp',p1);
set(obj,'dim',default_dim(obj));
```

FIGURE 28

Physics Modeling Methods

514

Function	Purpose
`appspec`	Return application specifications.
`bnd_compute`	Convert application-dependent boundary conditions to generic boundary coefficients.
`default_bnd`	Default boundary conditions.
`default_dim`	Default names of dependent variables.
`default_equ`	Default PDE coefficients/Material parameters.
`default_init`	Default initial conditions.
`default_sdim`	Default space dimension variables.
`default_var`	Default application scalar variables.
`dim_compute`	Return dependent variables for an application.
`equ_compute`	Convert application-dependent material parameters to generic PDE coefficients.
`form_compute`	Return PDE form.
`init_compute`	Convert application-dependent initial conditions to generic initial conditions.
`posttable`	Define assigned variable names and post-processing information.

FIGURE 29

00626098 .092600

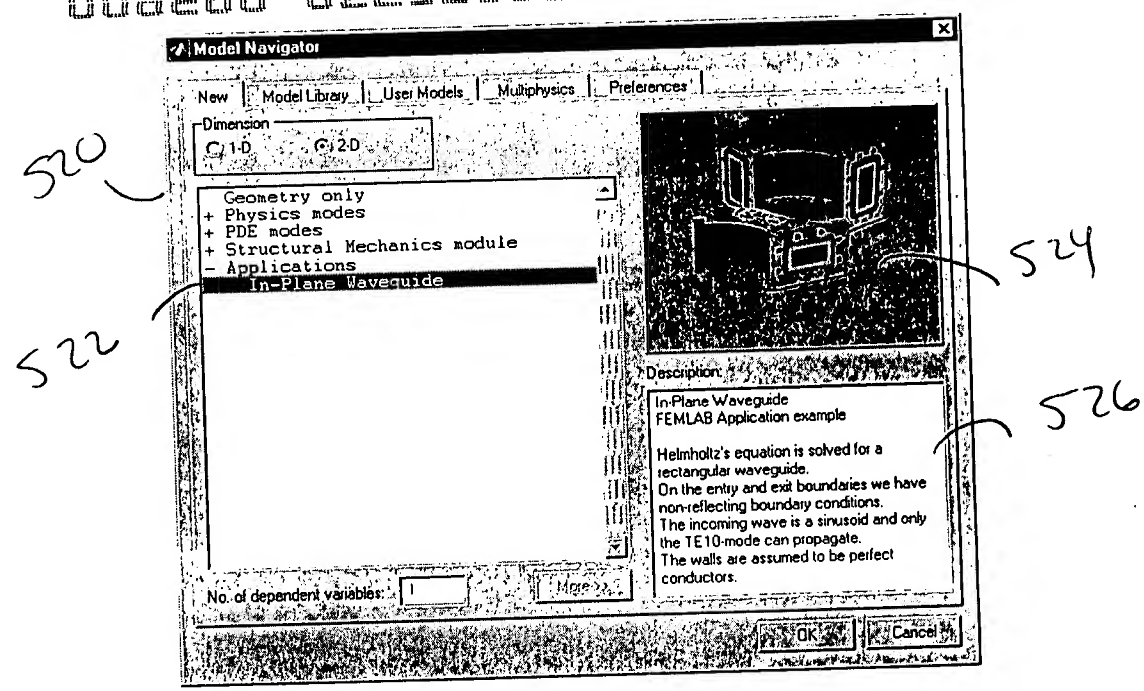


FIGURE 30

S30 $\Delta E_z + (2\pi i k)^2 E_z = 0$

S32 $k = \frac{1}{\lambda} = \frac{f}{c}$

S34 $\bar{n} \cdot (\nabla E_z) + 2\pi i k_x E_z = 4\pi i k_x \sin\left(\frac{\pi}{d}(y - y_0)\right)$

S36 $k^2 = k_x^2 + k_y^2$

S38 $k_x = \sqrt{\frac{1}{\lambda^2} - \frac{1}{(2d)^2}}$

S40 $n \cdot (\nabla E_z) + 2\pi i k_x E_z = 0$

S42 $E_z = 0$

S44 $f_c = \frac{c}{2d}$

FIGURE 31

```
function obj = flwaveguide(varargin)
%FLWAVEGUIDE Constructor for a Waveguide application object.

obj.name = 'In-Plane Waveguide';
obj.parent = 'flpdeac';

% FLWAVEGUIDE is a subclass of FLPDEAC:
p1 = flpdeac;
obj = class(obj,'flwaveguide',p1);
set(obj,'dim',default_dim(obj));
```

550

FIGURE 32

552

fem.user fields

Field	Description
geomparam	1-by-2 structure of geometry parameters.
entrybnd	Index to the entry boundary.
exitbnd	Index to the exit boundary.
freqs	Frequency vector

FIGURE 33

554

fem.user fields

Field	Description
startpt	Index of the lower left corner point of the waveguide.
type	Type of waveguide. (*'straight* or *'elbow*)

FIGURE 34

556

geomparam fields

Field	Description	Defaults for elbow	Defaults for straight
entrylength	Length of the entrance part of the waveguide.	0.1	0.1
exitlength	Length of the exit part of the waveguide.	0.1	Not used
radius	Outer radius of the waveguide bend.	0.05	Not used
width	Width of the waveguide.	0.025	0.025
cavityflag	Turn resonance cavity *on* or *off*.	0	0
cavitywidth	Width of the resonance cavity.	0.025	0.025
postwidth	Width of the protruding posts.	0.005	0.005
postdepth	Depth of the protruding posts.	0.005	0.005

FIGURE 35